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Pollutant Exposure Control System for Determination of the Effects of Exposure Regimes on Plant Growth

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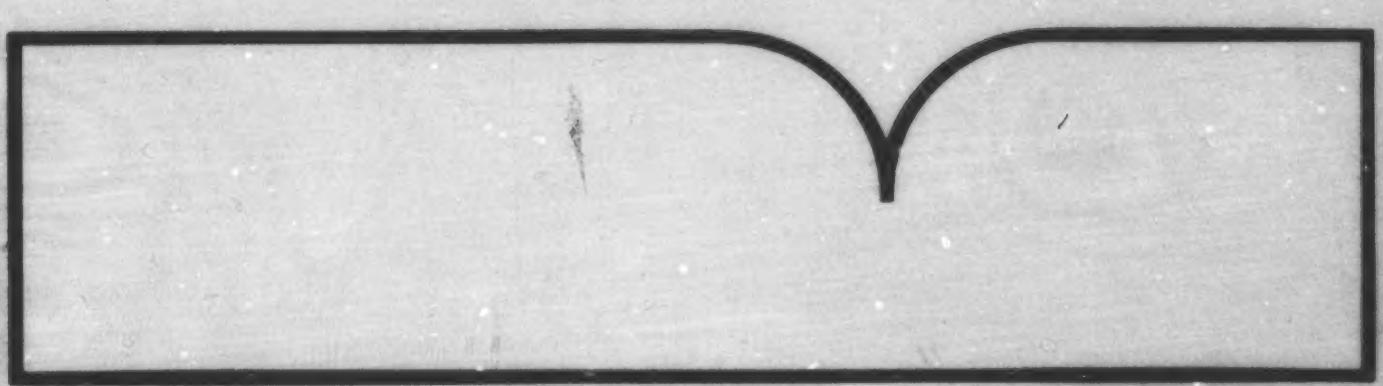

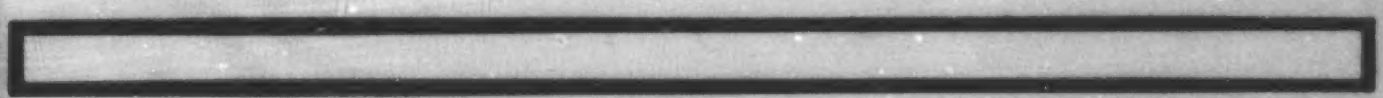

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A Pollutant Exposure Control System for Determination of the Effects of Exposure Regimes on Plant Growth

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16. ABSTRACT

In the field of air pollution effects research there is the need to examine the various components of pollutant dose expression (concentration, frequency, and duration) in order to assess each of their contributions to the observed response. The difficulty of selecting an appropriate statistic to characterize plant exposure has been summarized by Heagle and Heck. Pollutant exposure has been characterized by use of mean concentrations with varying averaging times (7-hr, weekly, month, or seasonal), the number of hours above a selected concentration, and the number of hours above selected concentration intervals. However, these values do not reflect the relationships of concentration, frequency and duration of exposures, and the plant response. The use of a mean implies that all concentrations are equally effective in elliciting a plant response and minimizes the contribution of peak concentrations. The mean treats low-level long-term exposures the same as high-concentrations short-term ones. Most exposure statistics are not directly correlated with each other and it is difficult to relate them to ambient air measurements of ozone which are usually reported as 1-hr means.

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ABSTRACT

A field-exposure research facility was constructed to determine the influence of various ozone exposure profiles (concentration, frequency, and duration) on plant response. The facility uses modified open-top chambers and an automated control system for continuous delivery and control of single or multiple pollutants over a growing season. Numerous exposure profiles (e.g., various episodic regimes, daily peak profiles with sinusoidal-type or square-wave type peaks) can be produced and controlled in all chambers. Ozone is produced by commercially-available generators; their outputs are controlled by an HP 41CV hand-held computer through a Hewlett-Packard Interface Loop System (HP-IL). Chamber microenvironmental data and ozone concentration data are collected continuously with a data acquisition system that includes mean hourly ozone concentration, air and soil temperature, relative humidity and solar radiation. The hourly ozone concentration in each chamber ranged from 2-12% of the requested concentration over a 174-day season. Initial studies with this facility compared the response of alfalfa and tall fescue growth to episodic and daily peak exposure profiles with equivalent integrated doses over the growing season. Over the period of three cuttings (133 days), growth of alfalfa was reduced more when exposed to the episodic profile than with the ozone exposure regime of daily peaks. Tall fescue growth was only slightly reduced over a period of three cuttings (90 days) when exposed to either regime.

INTRODUCTION

In the field of air pollution effects research there is the need to examine the various components of pollutant dose expression (concentration, frequency, and duration) in order to assess each of their contributions to the observed response. The difficulty of selecting an appropriate statistic to characterize plant exposure has been summarized by Heagle and Heck[1]. Pollutant exposure has been characterized by use of mean concentrations with varying averaging times (7-hr, weekly, month, or seasonal), the number of hours above a selected concentration, and the number of hours above selected concentration intervals. However, these values do not reflect the relationships of concentration, frequency and duaration of exposures, and the plant response. The use of a mean implies that all concentrations are equally effective in elliciting a plant response and minimizes the contribution of peak concentrations. The mean treats low-level long-term exposures the same as high-concentration short-term ones. Most exposure statistics are not directly correlated with each other and it is difficult to relate them to ambient air measurements of ozone which are usually reported as 1-hr means.

Several authors have reported the greater importance of concentration compared to exposure duration in causing injury in plants.[2,3,4,5] In addition to the importance of concentration and time, there is the dynamic nature of the exposure, i.e. constant or variable concentration over time. Musselman et al.[6] demonstrated that constant concentrations of ozone caused the same types of plant response as did variable concentrations at equivalent dose. But the variable concentration exposures caused a greater effect on the plants. These factors need to be considered in developing the appropriate air quality criteria statistic.

The Field Exposure Research Facility (FERF) at EPA's Corvallis Environmental Research Laboratory (CERL) was designed to provide research capabilities needed for comparative studies of experimentally developed exposure profiles of both single and mixed gaseous pollutants. The primary design criteria were: 1) minimal operator interaction outside of programming and quality assurance checks; 2) precision in control and delivery; 3) adaptability to changing research needs; and 4) simplicity of operation. The system chosen was an HP 41CV hand-held computer (Hewlett-Packard, Corvallis, Oregon) controlling delivery of pollutant through an interface loop system (HP-IL).[7,8] (mention of tradenames or commercial products does not constitute endorsement or recommendation for use). An HP 9825 table-top calculator interfaced with a multi-channel data logger (HP 3052A) (Hewlett-Packard, Corvallis) was used for continuous data acquisition. Following is a description of the system and results from the first year in operation.

SITE DESCRIPTION

The site plan for the field exposure research facility (FERF) is shown in Figure 1. There are 12 circular open-top exposure chambers arranged in three east-west rows. Each chamber has a separate air intake and is independently connected to the pollutant delivery and sampling system located in the climate-controlled support building on the south end of the site. Teflon sampling and

delivery lines are enclosed in insulated PVC pipe. Drip irrigation is used for nutrient delivery and watering; the microprocessor control system is situated just north of the central row of chambers. An outdoor nursery site, north of the exposure chamber, is used for holding plants before they are moved into the chambers.

Exposure Chambers:

The pollutant exposure chamber is a cylinder, 3 m in diameter and 2.4 m high, constructed of aluminum channel members and covered with polyvinyl chloride (PVC) film (Figure 2). The chamber is a modification of the Heagle et al. design.[9] A frustrum, having a truncated cone shape with a 2-m diameter opening, was added to the chamber top to reduce intrusion of ambient air for concentration uniformity within the chambers.[10,11,12] A rain cap was added 30 cm above the open-top to prevent rain fall on plants used in moisture stress studies and to prevent rain shadows within the chambers.

Ambient air is pulled through a fiberglass particulate filter and an activated charcoal filter into an axial-blade intake fan on the north-east side of the chamber (Figure 2). Airflow into the chamber is 304.8 cubic meters per minute, for a chamber air exchange rate of 1.5 times per minute. Ozone is delivered into the airstream between the fan box and the chamber. The airstream enters the chamber through a double-walled section of the chamber cover which encircles the chamber to a height of 1.2 m. The inner wall of this plenum is perforated with 2.5-cm holes at regular intervals to allow relatively slow, even movement of air into the chamber, with increased mixing of the incoming air. Air leaves the chamber through the top opening at positive pressure.

Ozone sampling lines and environmental sensor cables enter the chamber through the access pipe suspended in the chamber center. An open wooden framework approximately 10 cm off the ground supports the plant containers and the supply lines for the watering system (not shown in Figure). Worker access to the chamber interior is through a small, overlapping section of the plenum.

POLLUTANT DISPENSING and CONTROL

General Organization:

Figure 3 illustrates the overall organization of the pollutant delivery and control system. Ozone is produced by an ozone generator (Griffin Technics Corp, Lodi NJ, Model GTC-1A) using pure oxygen as the reaction gas to prevent undesirable pollutants and provide a stable production of ozone. The ozone concentration is regulated by direct control of the generator output by the HP 41CV. Ozone enters the chambers through a 12-port manifold and flow is controlled to each chamber by a toggle switch and a rotameter. Air in each chamber is sampled by Dasibi 1003-AH Ozone Monitors through a 1/4-inch (i.d.) teflon line hanging at approximately canopy height.

For the 1983 field season two different profile types, an episodic peak profile and a daily peak profile, were investigated. Two ozone generators and two control routines were required. One chamber for each exposure profile type

is used as a 'controlling' chamber. Continuous monitor readings from these chambers are used in the control system to alter generator output as needed. Ozone output to the other chambers is achieved by adjusting the individual chamber rotameters to a setting predetermined to give concentrations either equal to, or a stable proportion less than, the concentration in the controlling chambers.

Chamber ozone concentration is determined by sequential sampling of the chambers. The ozone data, as well as chamber environmental data, are collected by the automated data acquisition system.

Exposure Control:

The experimental exposure profiles are controlled by an HP 41CV hand-held computer, with all components of the exposure system addressed through a standard Hewlett-Packard interface loop system (HP-IL). Peripheral devices in the control system are connected as shown in Figure 4. The HP 41CV can access any component of the loop and thus control the production of ozone. Hourly ozone concentrations for each profile are stored on tape and accessed hourly to make step changes in concentration. During the hour, control of the chamber concentration is accomplished through continuous monitor feedback from one of the high concentration chambers of each profile type. For the 1983 field season, the HP-IL system is used for simultaneous control of only two exposure profile types. The system has the potential, however, to control up to 14 different profiles simultaneously.

For any exposure profile, the required ozone concentrations for each day and hour of the exposure are entered into the HP 41CV and stored on cassette tape (HP-82161A Digital Cassette Drive). During the exposure, the computer uses its on-board clock (HP-82182 Time Module) to access the concentration request for the current day and hour from the tape. The actual current chamber concentration is sampled continuously by the ozone monitors. The computer reads the concentration from the monitor as a 0 to 1 Volt DC signal (corresponding to 0-1 ppm ozone) through a digital multimeter (HP 3468A). The current request and the actual current concentration are compared, and the generator output is altered accordingly. The HP 41CV connects to the generator through an HP-IL/GPIO interface (HP 82165A). This device provides the capability to interface equipment, with general purpose input/output capability to the HP 41CV control circuit. For this interface to be compatible with the Griffin ozone generator, the computer signal must be converted from digital to analog form before it enters the generator. This is achieved with a D/A converter integrated circuit, custom built for this system. If a change in generator output is required by the controller, it sends an appropriate 0-10 V DC signal to the internal control circuit on the generator. A 0 V signal will result in a near zero ozone output; at 10 volts, ozone output is maximum. Decision algorithims in the controller software determine the appropriate signal in this range. Two separate algorithims can be evoked by the program: one which provides rapid, relatively coarse adjustment in concentration, normally used at each programmed change in concentration request; and the other which allows fine adjustment during periods of stable concentration between the programmed hourly step changes.

In addition to the peripherals required in the control system, a thermal printer (HP 82162A) is interfaced to the computer. Error messages, program failures, and user commands are printed automatically by the device.

DATA ACQUISITION SYSTEMS

The automated data acquisition system (DAS) consists of a HP 9825A desk-top computer (Hewlett-Packard, Wilsonville, Oregon) interfaced to a data acquisition system (HP 3052A). All data input is accessed through a multi-channel scanner and a digital voltmeter. Date and time functions required by the data acquisition software are handled through an HP-IB digital clock (HP 59309A).

Air Monitoring Data:

Chamber ozone concentration is acquired by sampling and monitoring each chamber sequentially through an automated sampling valve (Scanivalve Corp.) (Figure 4). For the 12 chambers used at the Field Exposure Research Facility, two monitors and two sampling valves are required. Two of the 12 chambers are used by the HP-IL control system and are not monitored through the sampling valve. Data from these two chambers are recorded continuously and acquired directly by the two monitors dedicated to the HP-IL system. The remaining 10 chambers are sampled on a time-share basis with the two sampling valves and two Dasibi monitors (5 chambers/monitor). The sampling valve consists of a solenoid drive (Scanivalve Corp. Model SAMS 6-12) and a samplivalve (Scanivalve Corp. Model S65). The device requires an external power supply and circuitry to allow the data acquisition system to control the switching.

Chamber air is pulled into the monitor through the scanivalve for 1 minute, then a series of 5 concentration readings are collected, averaged and the resultant value is stored in the HP 9825A memory. The 1-minute equilibration time is sufficient for the Dasibi monitors which have a time constant of 20 seconds to reach 90% full-scale; the strip chart tracings of monitor readouts are stable after 30 seconds with a known ozone source. The computer switches the scanivalve to the next chamber to be sampled. Each chamber is sampled for 1.4 minutes every 7 minutes over a period of 60 minutes for a total of 9 concentration readings collected on each chamber each hour. These readings are used to calculate the hourly average and standard deviation. To keep the chamber air in the sample lines current, a pump (Metal Bellows Corp. Model MB-41) continually pulls air through all the channels not currently being sampled. The pump operates at an air flow of 11.4 liters/minute, allowing for 4.7 air changes/minute/sample line.

The two HP-IL controlling chambers are sampled 48 times per hour by their dedicated monitors; the calculated hourly ozone values are stored on cassette tape in the DAS. In addition, ozone concentration in each of the two chambers used in the HP-IL control system is recorded continuously with a two-channel recorder (Leeds and Northrup Speedomax model 250). This recording provides a visual check on the status of the exposure profiles as well as a back-up record of ozone data. In the 1984 season, this system will be included in the HP-IL control system and the ozone concentration readings stored on cassette tape in addition to strip charts.

All exposure data accumulate in the HP-9825A memory for 24 hours, then hourly concentration means and standard deviations are calculated for each chamber. The data are printed out on paper tape and stored on cassette tape. Data from the cassette tapes are transferred to the PDP 11/70 mainframe computer through an HP 9825A computer equipped with an RS232 interface, and data formatting and transmission software.

Air Monitor Quality Assurance:

The ozone monitors were calibrated with a transfer standard[13] prior to use at the desired concentrations. The transfer standard was calibrated with a dedicated "UV standard" operated and calibrated in accordance with the procedures of Paur and McElroy.[14] To ensure accuracy, both standards were subjected to periodic performance audits. Instrument precision was checked weekly with a zero and span check. Monitors were returned to the CERL Instrument Laboratory for corrective action if the displayed value was greater than $\pm$10% of the known value of the calibration gas. The accuracy of the monitors was determined at the beginning and at the end of the season with a system audit. In this audit a known concentration of ozone is introduced into the sample line at each chamber and the displayed response of the monitor is compared to the known concentration. By introducing the known ozone concentration into the beginning of the sample line, the integrity of the entire system is tested. Daily operation of the monitors was checked by the on-site operator. Problems are noted in log books and any action taken by the instrument lab.

Daily effectiveness and reliability of the system was verified in two ways during the field season. First, all components of the system, including the generators, HP-IL control, data acquisition system, manifolds and rotameters were inspected twice daily, 7 days per week for successful operation. Any corrective measures required were taken immediately. The results are maintained in a daily checklist and log. Second, the ozone concentration data were collected by two independent sources which could be compared. One source was through the HP-IL control system and strip chart recording of the two controlled chambers, and the other was the hourly ozone concentration from each chamber compiled by the DAS at the end of each 24-hr period. A visual check of the strip chart recording of each profile ensured proper control and delivery during each day, and actual hourly ozone concentration values from the two sources could be compared for proper functioning of the data acquisition system and dedicated monitors.

Environmental Data:

Chamber microenvironmental data are collected daily. Parameters include chamber air temperature, soil temperature, relative humidity, and solar radiation. All parameters except solar radiation are automatically acquired and stored by the data acquisition system.

Each chamber is equipped with an air temperature thermistor (Omega Engineering Corp. Model ON 405-PP) suspended at approximately canopy height below the central chamber access pipe. The thermistor is protected with a 5-cm diameter styrofoam shade. In addition, two chambers are equipped with two

subsoil thermistors (Omega ON 401-PP) located at 10-cm depth in two border row pots on opposite sides of the chambers. Chamber relative humidity data are collected via a thin-film capacitance device (Vaisala HMP-14). The probe is mounted horizontally, approximately 10 cm above the pot tops near the chamber center.

The data acquisition system is programmed to scan all the environmental sensors once every 1.4 minutes. The data are stored in the HP 9825A memory, and at midnight the 24-hr mean and the maximum and minimum values are calculated from the accumulated data for each environmental sensor. The resulting values are printed on paper tape and stored on cassette tape.

Solar radiation data are collected each day with a quantum sensor (LI-COR Model LI-190SB) mounted at approximately 10 cm above the plant canopy near the chamber center. The sensor is connected to a solar monitor (LI-1776) housed in the control building. The monitor is programmed to integrate daily solar irradiance as photosynthetically active radiation (400-700 nm waveband) for a 24 hour period. Data are reported as Einsteins per square meter per day. The solar monitor is equipped with memory so that each day's data may be collected on the following day. The irradiance data are then entered into Inform data files on the PDP 11/70 mainframe computer.

RESULTS AND DISCUSSION

Chamber Ozone Distribution:

A primary concern in the operation of these modified open-top chambers is with the degree of stability and control of chamber pollutant concentration. The concentrations must be stable, predictable, and relatively uniform within the plant canopy. Previous work with the open-top chambers in the ambient environment indicates that ozone concentrations within the chambers remains stable up to wind speeds of 15 km/hr.[15] Long-term distribution of ozone within our chambers was found to be stable with wind speeds of 8-20 km/h. The distribution of ozone was assessed at 22 and 50 cm above the pot supports by measuring ozone concentrations, 5 times each day on 3 different days, at 20 points evenly located around the chamber. Ozone was introduced to the chambers at 0.08-0.10 ppm and measurements taken for 15 minutes after 15-minute equolibration. During the test, ozone was sampled continuously from a reference point 22 cm high, below the central access pipe and simultaneously from a mobile sample line suspended at the designated point. In general, the concentration distribution was very uniform (Figure 5). The data are expressed as percentage of the central reference point. The point concentrations of ozone at both sampling heights varied by less than 10% from the central reference, indicating no substantial horizontal variation in concentration distribution. However, a few points at the periphery were exception, exhibiting a 20% difference. These points were 20 cm from the inner wall of the plenum and the high point concentrations may be due to the greater air velocity at the chamber periphery discussed by Heagle et al.[15] At the 50-cm sampling height, 3-12% differences were observed with the 22-cm reference sample. The horizontal variation at this height ranged from 2-15%. The distribution observed within our chamber appeared to be in general agreement with that observed for other open-top chambers.[15]

Chamber Sampling Efficiency:

Sampling efficiency was not affected by sample line length to the various chambers and no line loss was demonstrated. Table 1 presents the results from the beginning of the 1983 field season. Ozone (0.12 ppm) was introduced to the chambers and simultaneous readings were taken for 30-60 minutes from the same position inside each chamber and in the control building. The variation between readings was 7-8%, with the accuracy of the monitors with ±10%. The sample line length between each chamber and the monitors inside the control building ranged from 19 to 42 m. Another systems audit was conducted at the end of the field season; a known source of ozone was introduced at the chamber as described above for air monitoring quality assurance. The difference between chamber monitor readings and the readings taken from the sample line were 6-10% in all chambers with 0.09 ppm ozone. This difference represented less than 3% line loss.

Site Performance:

The facility performed relatively well in its first season, demonstrating the ability to deliver and control two types of ozone profiles with different frequency and duration of peak events over a period of 174 days. A representative 30-day period for the two exposure profiles is shown in Figure 6. The peak values of the expisodic profile occured at 1400 or 1500 hr and the peak values of the daily profile occured each day at 1400 hr. The concentration increased slowly beginning about 0700 hr and following the peak, the concentration decreased relatively rapidly to backgroud at about 1800 hr. Both the requested and the actual hourly ozone concentrations are plotted. Over the season, the actual profile corresponded well with the requested profile, even though there were a few instances of loss in control of delivery.

There were only 38 incidents of ozone control and delivery failure over the 174-day period, less than 2% of the total exposure time. None was longer than 8 hours and most were only 1-2 hours in length. In only three instances did the loss in control result in a higher than requested ozone concentration and these occurred at night. Most of the failures could be traced to area-wide power outages and failures in the circuitry of the Griffin ozone generators.

The deviation in actual hourly ozone concentration from the requested ozone concentration for each chamber is shown in Table 4. The accuracy of the system monitors was within ±10%. In general, the majority of all deviation from the requested was .01 ppm or less, which is at the limit of accuracy of the monitors. The frequency in deviation from requested hourly ozone concentrations in the two controlling chambers (chamber 1 and 9) is very slight. In these chambers the mean hourly ozone concentration was within ±.01 ppm of the requested concentration 83-87% of the time. The mean ppm difference in the range of >.01-<.05 for these chambers was .025 ppm. However, in chambers where the concentration is controlled by flow rate through the rotameters the frequency of deviation was greater. The frequency of ppm differences in the range of .01-.05 increased to 23-35%. The average value in this range of deviation was .032 ppm. Hourly concentration differences greater than .05 ppm occured 8% or

less of the total exposure time. This problem is being rectified for the 1984 field season with improved calibration procedures for the rotameters. The maximum deviation in any chamber was 0.15 ppm and this particular incident occured at night.

The seasonal air statistic for each chamber expressed as the 7-hour mean over 133 days (9 a.m.-4 p.m.) (Table 2) or as an integrated exposure index (sum of hourly mean ppm $\geq$ 0.07 ovre 133 days) (Table 3) showed relatively good agreement between requested and the actual achieved values. All differed by less than 6% except chambers 8 and 12 and these experienced seasonal values 8-13% less than the request. The four control chambers with charcoal-filtered air exhibited a seasonal 7-hour mean of 0.011 ppm or less.

Alfalfa Yield Response:

The overall objective of ozone-effects research at CERL is to characterize the important component(s) of ozone dose in elliciting plant growth response. During the first year of the project the difference in growth response of two important forage crops, alfalfa and tall fescue, was examined during exposures to two different types of exposure profiles. One was a 30-day episodic profile of varying peak frequency, concentration and duration. This profile was repeated every 30 days throughout the growing season. The second was a daily peak profile of equivalent peak concentration and duration each day. The two profiles were constructed using the 1978 SAROAD database[16] for a selected midwestern site that has substantial acreage in hay crops (Conneaut, OH). To characterize the reported ozone air quality at specific sites the methods described by Lefohn and Benedict[17] was applied using the percentile information in the SAROAD database. The profiles were designed to have an equivalent integrated exposure index over a 30-day and 5-month growing season. A frequency distribution of the episodes for April-October above or equal to the selected integration value was developed as well as the extent of the rise and decline in daily ozone distribution for the selected site. From this frequency distribution and the shape of the ozone peak, two experimental exposure profiles were developed. Using the SARAOD datasets, a 'typical' episodic profile was developed that reflects 1) the number of hourly ozone values above an integration value, 2) the continuous number of days an event lasted, and 3) the length of time between ozone events. The value of 0.07 ppm selected for an integration value did not represent any biological threshold. The seasonal integrated exposure index for the two profiles were shown in Table 3 for the alfalfa growing season.

Using these two profiles over a 133-day growth period for alfalfa, it was observed that with both profile types growth was reduced with increasing ozone concentration and the growth reductions apparently were greater with episodic ozone exposure than with daily exposures at the high concentration. Final harvest weights are given for the three cuttings over the season in Table 5. By the second cutting, the shoot dry weight was reduced 75% and 90% with daily and episodic exposures, respectively. These differences were significant at the second and third cutting. It is important to note that the 7-hr means for these two profiles do not reflect the observed growth response. The episodic profile has a smaller seasonal mean, yet causes greater yield reductions. In constrast to alfalfa, tall fescue yield at three cuttings over a 90-day growing season was only slightly reduced, and no differences in response to the two different profiles was apparent.

REFERENCES

1. Heagle, A.S. and Heck, W.W., "Field methods to assess crop losses due to oxident air pollutants", in Crop Loss Assessment: Proceedings of E.C. Stakman Commemorative Symposium. P.S. Teng and A.V. Krupa Eds. University of Minnesota, Agricultural Experimental Station; Miscellaneous Publication No. 7, Minneapolis, pp. 296-305, 1980.

2. Heck, W.W., Dunning, J.A., and Hindawi, I.J., "Ozone: Non-linear relation of dose and injury in plants". Science 151:577 (1966).

3. Bennett, J.H., "Foliar exchange of gases", in Handbook of Methodology for the Assessment of Air Pollution Effects on Vegetation. Heck, W.W., S.K. Krupa, and S.N. Linzon, Eds. Air Pollution Control Association, Pittsburgh. 1979, pp 10-1 to 10-29.

4. Heck, W.W. and Tingey, D.T., "Ozone time-concentration model to predict acute foliar injury", in Proceedings of the Second International Clean Air Congress. H.M. Englund and W.T. Beery, Eds. Academic Press, New York, pp. 249-255, 1971

5. Reinert, R.A. and Nelson, P.V., "Sensitivity and growth of twelve elatior begonia cultivars to ozone". HortScience 14:747 (1979).

6. Musselman, R.C., Oshima, R.J., and Gallavan, R.E.,"Significance of pollutant concentration distribution on the response of red kidney beans to ozone." J. Amer. Soc. Hort. Sci. 108:347 (1983).

7. Kane, Gerry, Harper, Steve, and Ushijima, David, The HP-IL System: An Introductory Guide to the Hewlett-Packard Interface Loop. Osborne/McGraw-Hill, Berkeley, California, 1982.

8. Katz, Robert. "The Hewlett-Packard interface loop HP-IL: Unique two-wire system allows low-cost data collection", BYTE 7(4):76 (1982).

9. Heagle,A.S., Body, D.E., and Heck, W.W., "An open-top field chamber to assess the impact of air pollution on plants". J. Environ. Quality 2(3):365 (1973).

10. Kats, G., Thompson, C. R., and Kuby, W.C., "Improved ventilation of open top greenhouses," JAPCA 26:1089 (1979).

11. Davis, J.M. and Rogers, H.H., "Wind tunnel testing of open top field chambers for plant effects assessment," JAPCA 30(8):905, (1980).

12. Buckenham, A.H., Parry, M.A., Whittingham, C.P. and Young, A.T., "An improved open-topped chamber for pollution studies on crop growth." Environmental Pollution (Series B) 2:475 (1981).

13. McElroy, F.F., "Transfer standards for calibration of air monitoring analyzers for ozone". U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Research Triangle Park, N.C. EPA-600/4-79-056, 150 pp. (1979).

14. Paur, R.J. and McElroy, F.F., "Technical assistance document for the calibration of ambient ozone monitors. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Research Triangle Park, N.C., EPA-600/4-79-057, 69 pp. (1979).

15. Heagle, A.S., Philbeck, R.B., Rogers, H.H., and Letchworth, M.B., "Dispensing and monitoring ozone in open-top field chambers for plant-effects studies". Phytopathology 69:15 (1979).

16. "Air Quality Data - 1978 Annual Statistics", U.S. Environmental Protection Agency, Monitoring and Data Analysis Division, National Air Data Branch, Research Triangle Park, N.C., EPA-450/4-79-037, 1979.

17. Lefohn, A.S. and Benedict, H.M., "Development of a mathematical indices that describe gasous pollutant exposure, frequency, and duration", Atmospheric Environment 16(10):2529 (1982).

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Table I. Ozone concentrations in eight chambers measured in situ and through the sample lines.

CHAMBER NO.	MONITOR LOCATION	OZONE PPM (S.D.)
1	Chamber	0.12 (0.02)
	Building	0.12 (0.02)
2	Chamber	0.12 (0.01)
	Building	0.11 (0.01)
3	Chamber	0.12 (0.01)
	Building	0.11 (0.01)
6	Chamber	0.13 (0.01)
	Building	0.13 (0.01)
8	Chamber	0.15 (0.02)
	Building	0.14 (0.02)
9	Chamber	0.13 (0.03)
	Building	0.12 (0.02)
11	Chamber	0.12 (0.02)
	Building	0.12 (0.01)
12	Chamber	0.15 (0.01)
	Building	0.14 (0.02)

Table II. Seasonal 7-hour mean ozone concentration in each chamber for the 133-day growing season for alfalfa.

CHAMBER	PROFILE	7-HR MEAN (ppm) ACTUAL	7-HR MEAN (ppm) REQUEST	PERCENT DIFFERENCE
1	High Daily	.099	.103	3.9
8	High Daily	.092	.103	12.0
3	Low Daily	.075	.078	3.8
12	Low Daily	.072	.078	8.3
9	High Episodic	.085	.088	3.4
6	High Episodic	.083	.088	6.0
2	Low Episodic	.064	.066	3.0
11	Low Episodic	.063	.066	4.8

84-104.3

Table III. Seasonal integrated ozone exposure in each chamber for the 133-day alfalfa growing season.

CHAMBER	PROFILE	EXPOSURE (ppm-hr) ACTUAL	EXPOSURE (ppm-hr) REQUEST	PERCENT DIFFERENCE
1	High Daily	113.23	119.59	5.3
8	High Daily	104.45	119.59	12.6
3	Low Daily	63.24	66.53	4.9
12	Low Daily	59.10	66.53	11.2
9	High Episodic	117.85	113.96	3.3
6	High Episodic	116.68	113.96	2.3
2	Low Episodic	72.90	68.68	5.8
11	Low Episodic	66.74	68.68	2.9

84-104.3

Table III. Seasonal integrated ozone exposure in each chamber for the 133-day alfalfa growing season.

CHAMBER	PROFILE	EXPOSURE (ppm-hr) ACTUAL	EXPOSURE (ppm-hr) REQUEST	PERCENT DIFFERENCE
1	High Daily	113.23	119.59	5.3
8	High Daily	104.45	119.59	12.6
3	Low Daily	63.24	66.53	4.9
12	Low Daily	59.10	66.53	11.2
9	High Episodic	117.85	113.96	3.3
6	High Episodic	116.68	113.96	2.3
2	Low Episodic	72.90	68.68	5.8
11	Low Episodic	66.74	68.68	2.9

Table IV. Deviation of actual hourly ozone concentration from the requested hourly ozone concentration in each treatment chamber over 154 days of exposure.

		Frequency (%) in Deviation (±) from Requested Ozone (ppm)				
Chamber	Profile	0	≤.01	>.01-≤.05	>.05-≤.10	>.10
1	Daily	12	71	15	2	1
8	Daily	4	57	35	3	1
3	Daily	1	66	30	3	0
12	Daily	1	56	33	8	1
9	Episodic	22	65	11	1	1
6	Episodic	4	67	26	2	1
2	Episodic	1	61	29	6	2
11	Episodic	3	72	23	1	1

Table V. Alfalfa shoot dry weights (geometric means) of the three cuttings over a 133-day growing season. Cuttings were made at time of 10% flowering (exposure day 57,91, and 133). Two concentrations (100 and 75%) of each profile type are given with the 133-day seasonal 7-hr mean (9 a.m.-4 p.m.) and integrated dose (sum of ppm $\geq$.07). N = 16 for charcoal-filtered air control; N = 8 for each ozone treatment. Standard geometric deviation = 1.9570.

EXPOSURE	7-HR MEAN (ppm)	INTEGRATED DOSE (ppm-hr)	CUTTINGS (g) 1	2	3
Control	.011	0	2.23	4.99	4.51
Daily	.076	63.24	1.67	2.42 [a]	2.53
Episodic	.066	66.74	2.25	2.49 [a]	2.15 [a]
Daily	.103	113.23	0.50 [a]	1.26 [ab]	1.50 [ab]
Episodic	.088	117.85	0.62 [a]	0.49 [ab]	0.39 [ab]

[a] = Significant reduction from control (Dunnett's Test)

[b] = Significant difference between Daily and Episodic (t-test α=.05)

FIGURE LEGENDS

Figure 1. Site Plan for the Field Exposure Research Facility.

Figure 2. Cut-away View of Open-Top Exposure Chamber.

Figure 3. Schematic Diagram of Ozone Dispensing System

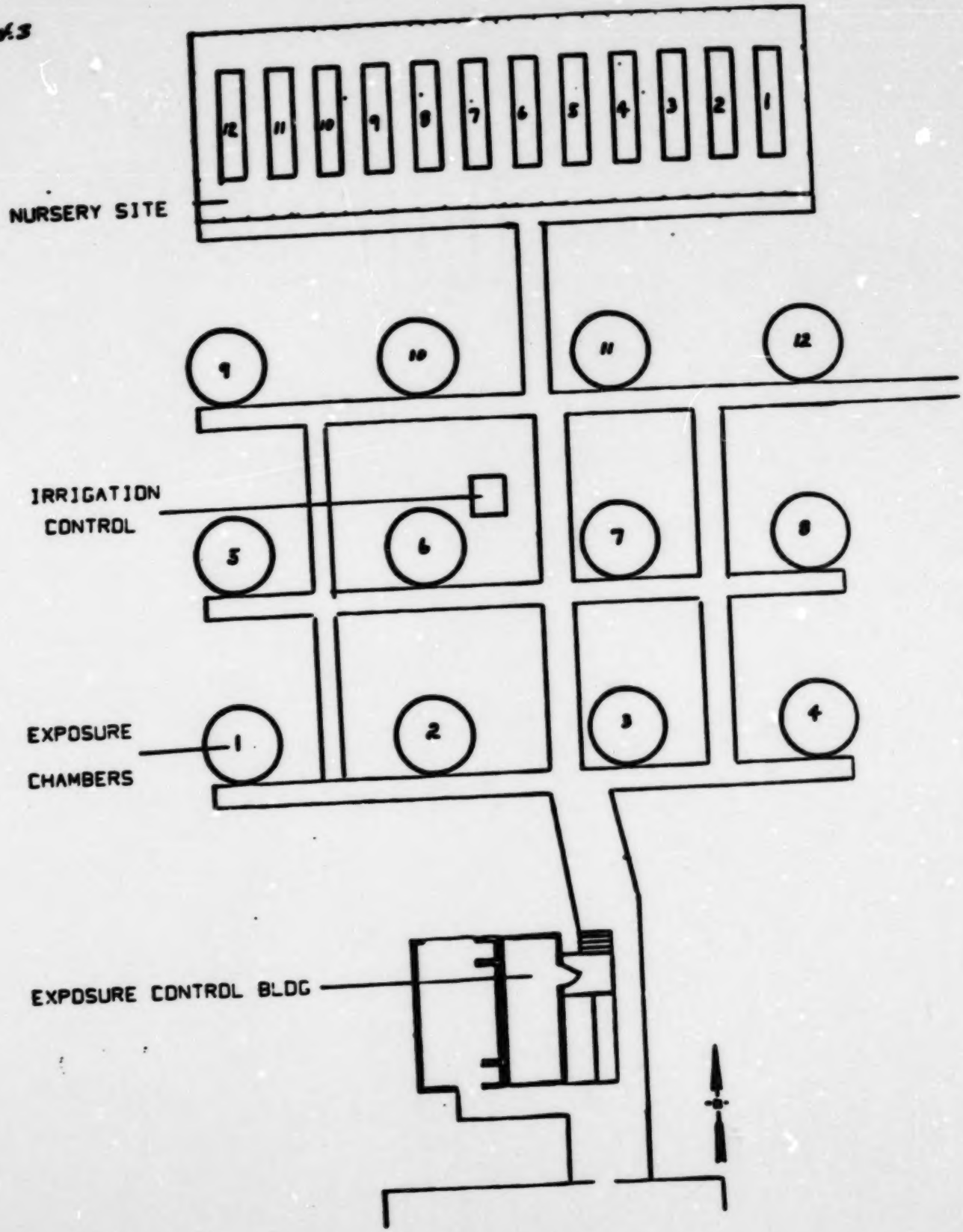
Figure 4. Schematic Diagram of HP-IL Control System

Figure 5. Ozone Concentration Distribution in Open-Top Exposure Chambers at A) 22 cm and B) 50 cm sampling heights above the pot supports. The data are expressed as percent of central reference point at the 22-cm height. The sampling points were arranged in concentric circles at 15 cm from the inner wall of the plenum and at 70 cm from the wall. The central reference sampling point was at 1.5 m.

Figure 6. Ozone Exposure Profiles for 1983 Season. The actual ozone concentration (——) and the requested concentration (-----) for each hour over a 30-day period is shown for both the episodic (A) and daily peak (B) profile.

Fig 1

84-1043


12
11
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IRRIGATION
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CHAMBERS
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EXPOSURE CONTROL BLDG

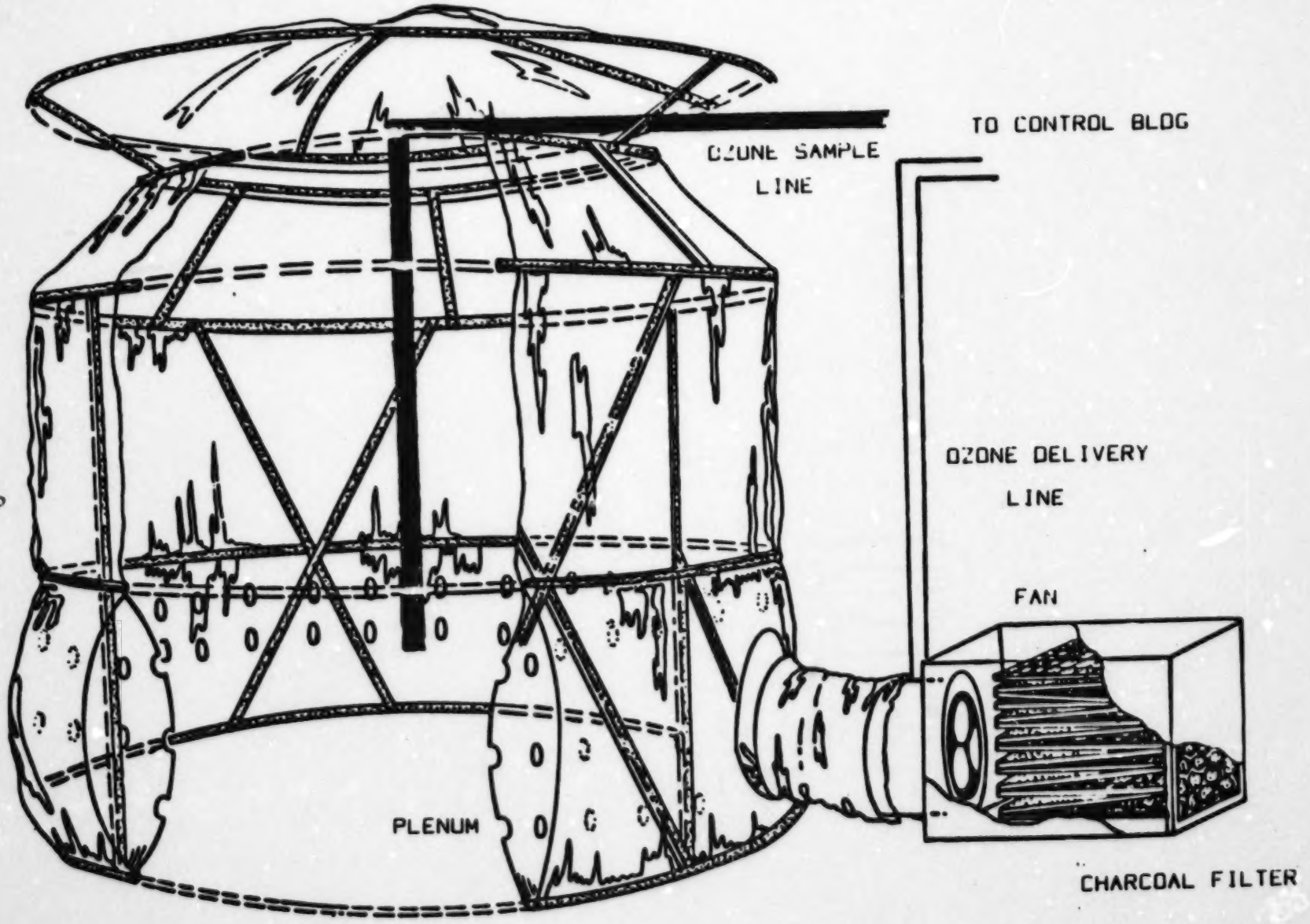
TO CONTROL BLDG
OZONE SAMPLE LINE
OZONE DELIVERY LINE
FAN
PLENUM
CHARCOAL FILTER

fig 2
sq-rod.3

OZONE DISPENSING SYSTEM

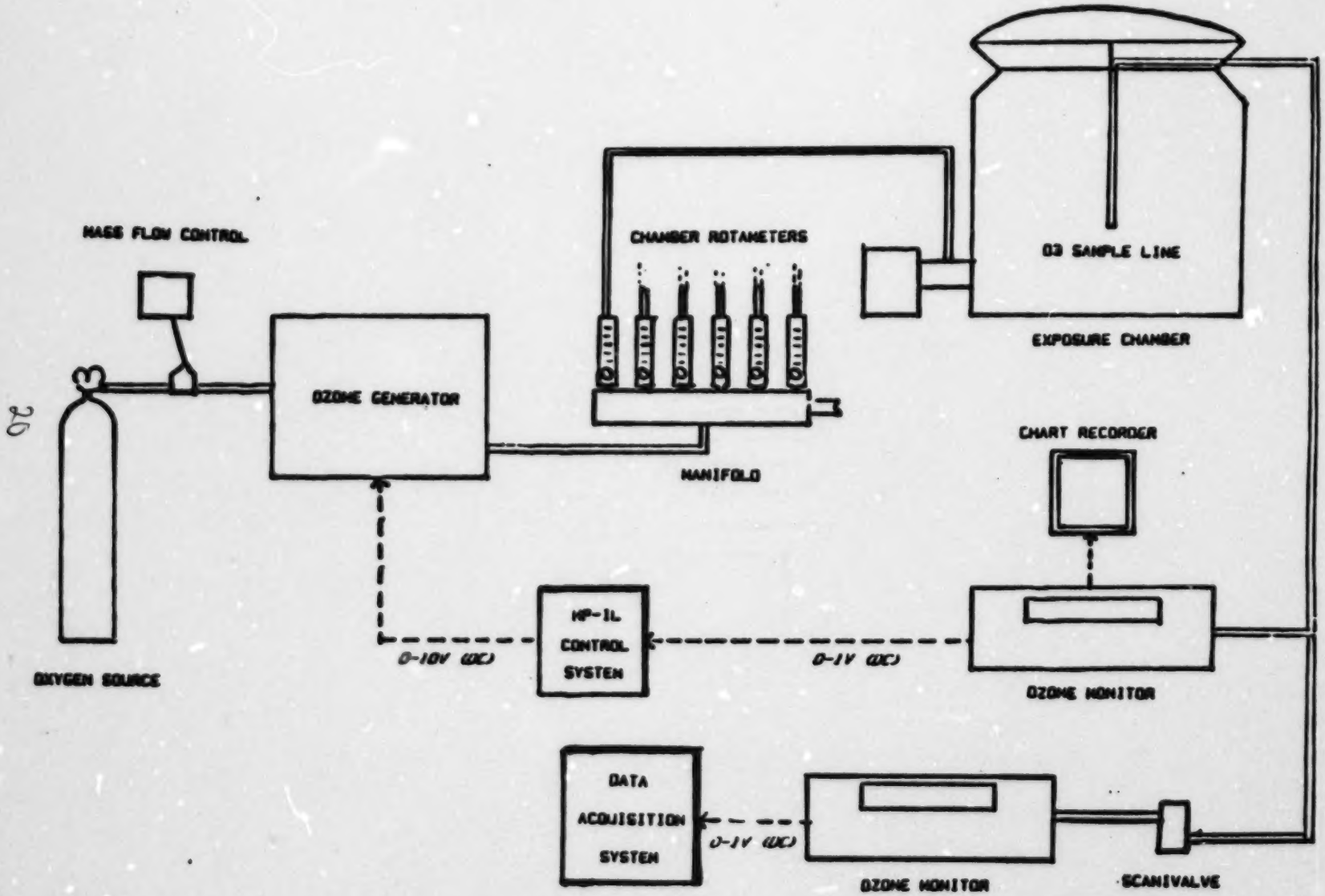

Fig 4

84-104.3

HP-IL CONTROL SYSTEM

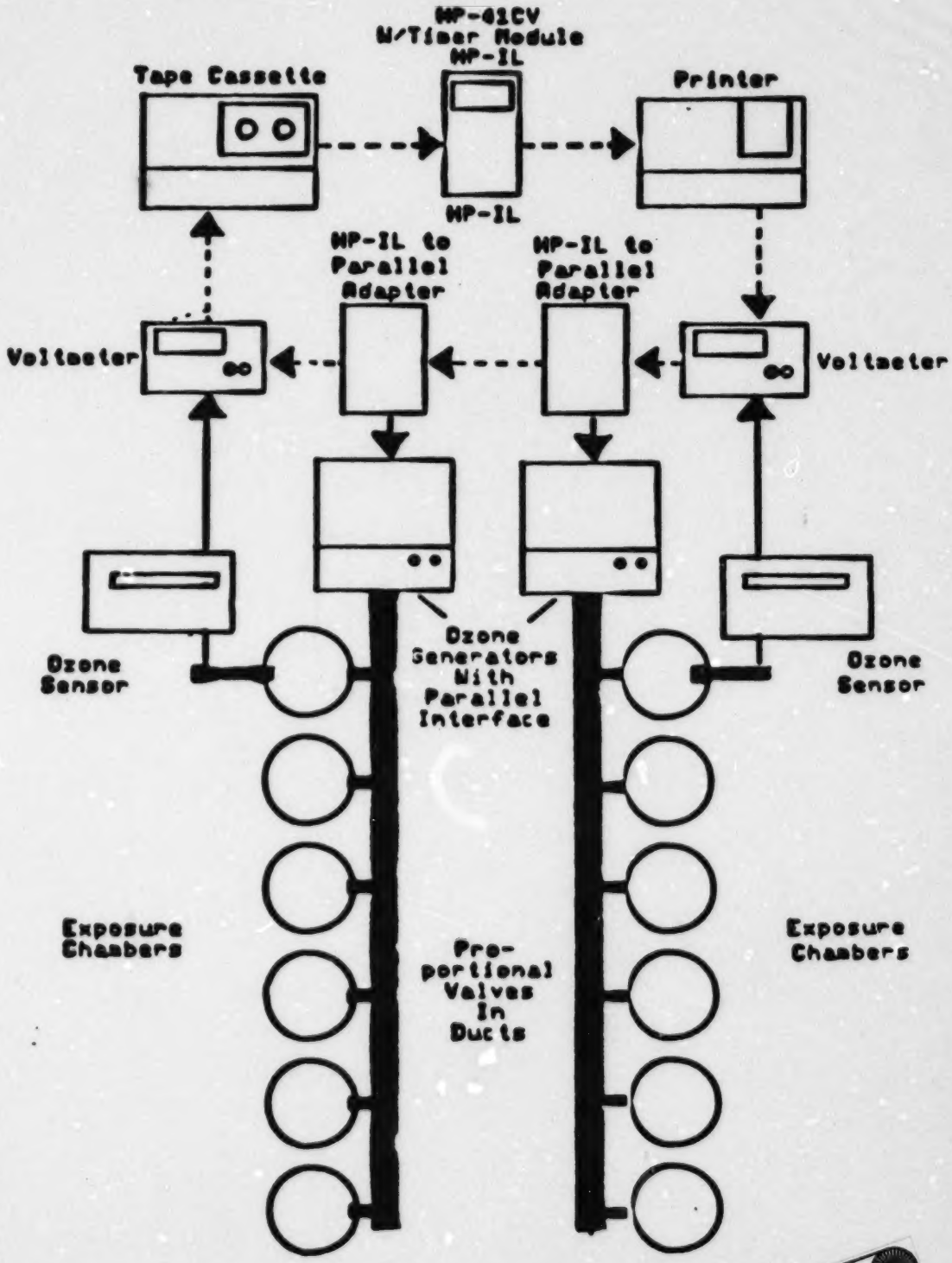

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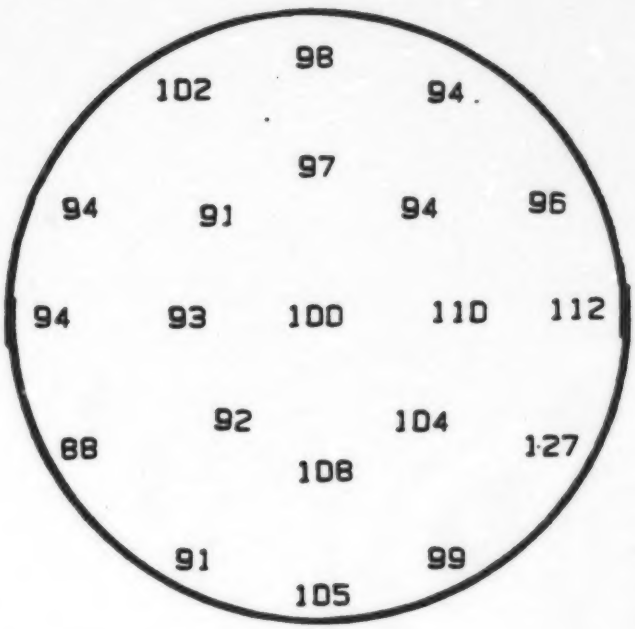
Fig 5
84-104.3

A. 22 CM HEIGHT



B. 50 CM HEIGHT

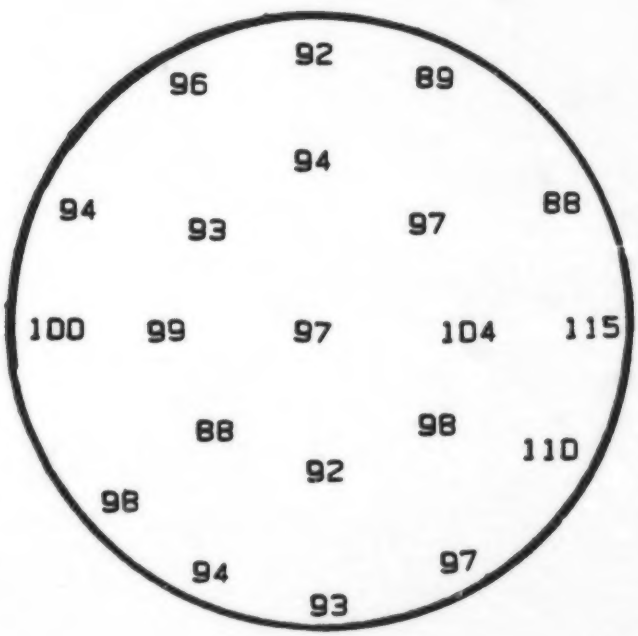
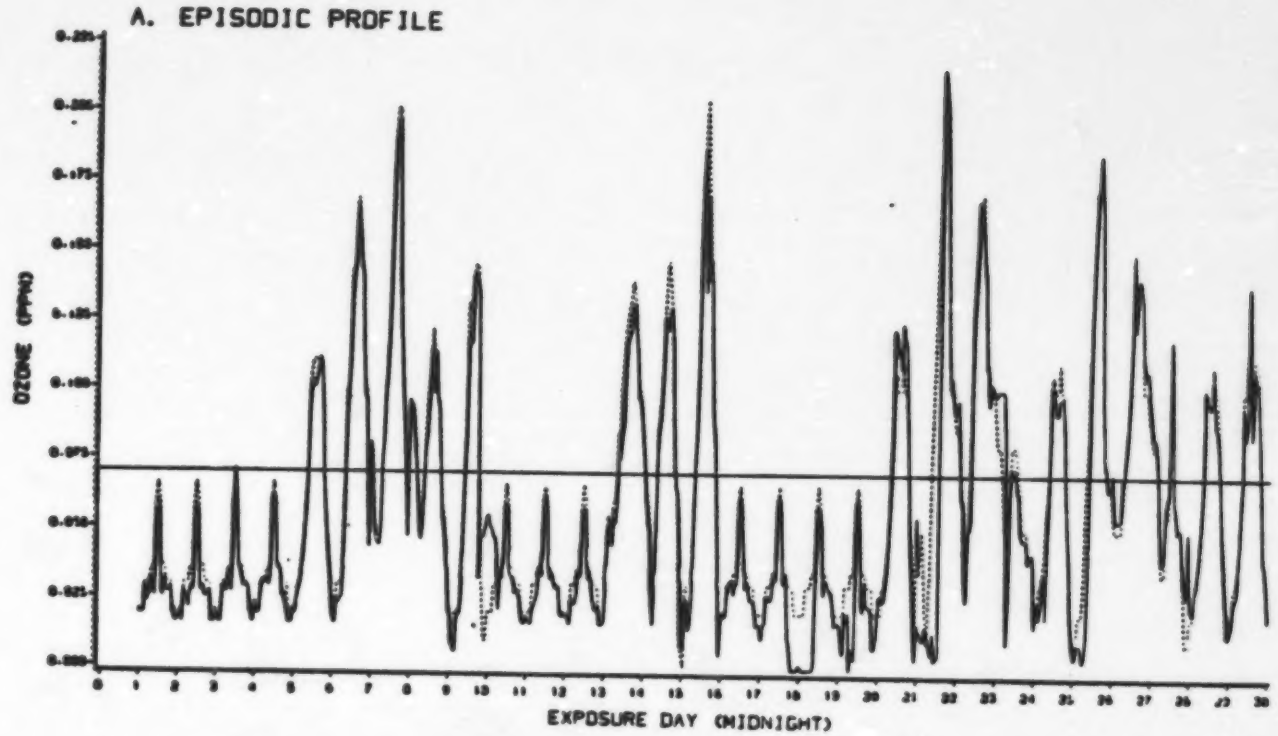
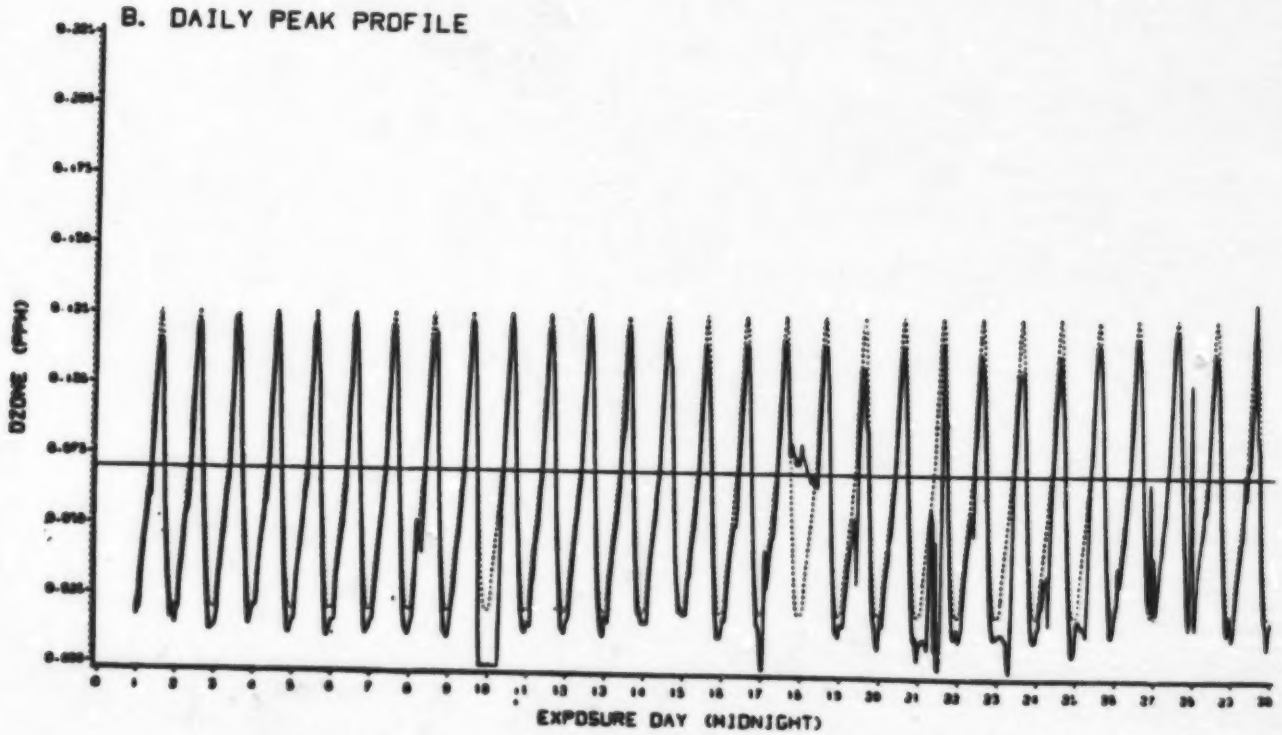


Fig 6
84-104.3


A. EPISODIC PROFILE
OZONE (PPM)
EXPOSURE DAY (MIDNIGHT)


B. DAILY PEAK PROFILE
OZONE (PPM)
EXPOSURE DAY (MIDNIGHT)